

## **MODELLING PERFORMANCE OF WATER-ONLY CYCLONE AS A GRAVITY SEPARATOR FOR FINE COAL CLEANING**

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### **ABSTRACT**

The performance of a gravity separator treating coal is characterized by plotting a Tromp distribution curve. In this study semi-empirical performance models have been employed to characterize the performance of water-only cyclone on the basis of experimental data modelling for fine coal cleaning. Experiments have been conducted in the laboratory on a 100 mm water only cyclone. Raw coal used for the experiments belong to Patherdih colliery in the Eastern part of India. Washability studies have been undertaken to determine the gravity separation for a desired coal quality. The Mayer curve has been employed to plot float-and-sink analysis from which the Tromp distribution curve has been constructed. A reduced efficiency curve has been obtained and attempts have been made to describe the behaviour using a Rosin-Rammler type distribution function characterizing the performance of the cyclone. A simplified approach has been purposed to estimate the model parameters.

**Keywords :** Water-only cyclone, Modelling performance, Fine coal cleaning.

### **INTRODUCTION**

Indian coals have very high ash content as well as high inorganic matter content and have difficult washability characteristics. Therefore, for Indian coals, fine crushing is essential for liberation of mineral matters and hence fine coal cleaning process is getting more attention by process engineers. Gravity concentration of minerals and coal has traditionally been recognized as a low cost and environmental friendly process for the separation of minerals. Gravity separation operations involving dense medium can be classified into two broad categories : manufactured medium and autogenous medium

devices. In the former class, the separation takes place in a liquid medium that is manufactured to have a density intermediate between the densities of the materials that are to be separated. Dense medium cyclone falls under this category. The most common manufactured media used in industry is slurry of finely ground magnetite in water. In autogenous medium devices, the particulate material itself makes an environment that has an effective density that will induce separation of particles of different densities by stratification. Water-only cyclone is an example of autogenous separator.

The application of cyclone separator for fine coal cleaning has been widely reported in the available literature<sup>[1-3]</sup>. These studies have demonstrated the potential application of cyclones in coal preparation to clean fine coal where the differential specific gravity between coal and shale is small. In India, a major portion of metallurgical coal is beneficiated by the dense medium cyclone process. However, due to the difficulties in magnetite recovery, media control, and associated operating costs, dense media has certain limitations for cleaning fine coal. On the other hand, water-only cyclones provide low-cost, low-maintenance solution to efficient recovery of hard to separate materials.

In the present work, studies have been carried out on high ash coal from Patherdih colliery using water-only cyclone. Experiments have been conducted in the laboratory on a 100 mm water-only cyclone. The clean coal product and the refuse obtained by treating the coal sample have been subjected to washability studies to determine the gravity separation for a desired coal quality. The Mayer curve has been generated from float-and-sink analysis data to predict the cleaning properties of coal. The Tromp distribution curve has been constructed from float-and-sink washability analysis data for clean coal and refuse to determine the specific gravity of separation for a given ash content. A reduced efficiency curve has been obtained and attempts have been made to describe the behaviour using a Rosin-Rammler type of formalism for estimating the performance. Model parameters of the reduced efficiency curve have been estimated by simplifying the model equation into linear forms and then applying least squares technique. The

details of the experimental programme and the methodology adopted are discussed in the subsequent sections.

### **Performance Modelling of the Cyclone**

Attempts have been made to model cyclone operation both theoretically and empirically. Development of high speed computers has been facilitated the numerical solution of the equations for fluid dynamics and thus rekindled on interest in theoretical modeling<sup>[4-6]</sup>. Despite of potential of theoretical models, they have not made a significant impact on the prediction of cyclone performance. Also such solutions are computationally intensive and time consuming. On the other hand, empirical mathematical models of the cyclone have received considerable attention for practical application<sup>[7-9]</sup>.

Empirical cyclone models are based on the observation that the probability of a particle reporting to one of the product streams is dependant upon the particle settling characteristics, or size. The principle of operation of the cyclone is based on the concept of the terminal settling velocity of a solid particle in a centrifugal field. The fine coal and water slurry is fed tangentially under pressure into the cyclone when lighter clean coal fraction is concentrated toward the centre of the cyclone and exits through the vortex finder. The heavy refuse is concentrated near the walls of the cyclone and exits through the apex.

## **EXPERIMENTAL**

### **Experiments with Water-Only Cyclone**

Experiments on a water only cyclone have been conducted in the laboratory using Patherdih coal of Eastern India. A given amount of solid and water were mixed in the feed tank to achieve solid of desired percentage by weight in the feed pulp. The feed slurry was pumped at the required inlet pressure. Samples from both the overflow and underflow slurry streams were collected simultaneously for a fixed interval of time. The slurry and solid weights of the products were measured and solid samples after drying were used for size analysis. Washability studies have been conducted for the cyclone overflow and underflow to determine the gravity of separation.

## Washability Studies

Washability analysis for Patherdih coal samples using heavy organic liquids with a density from 1.4 to 2.0 g/cm<sup>3</sup> was conducted in the laboratory. The dry weight of each fraction was determined and each was analyzed for ash content. The reconstituted washability of original sample was calculated from washability of sizes of cumulative overflow and cumulative underflow.

## RESULTS AND DISCUSSION

### Construction of Mayer Curve

The Mayer curve, known as the M-curve, provides a useful tool for float-and-sink analysis to predict the results of cleaning properties of coal<sup>[10]</sup>. The M-curve has been constructed by plotting both the cumulative weight percent on the ordinate scale and the cumulative average ash percent on the abscissa scale (Fig. 1). Diagonal lines were drawn from the origin to intersect the cumulative average ash axis at each cumulative ash value from float-and-sink analysis. Each cumulative ash value was then plotted on its respective diagonal at the intersection of the corresponding cumulative ordinate. The M-curve was drawn through these points. The Mayer curve provides a predictive capability to estimate the cumulative weight percent (yield) for a given cumulative ash percentage.

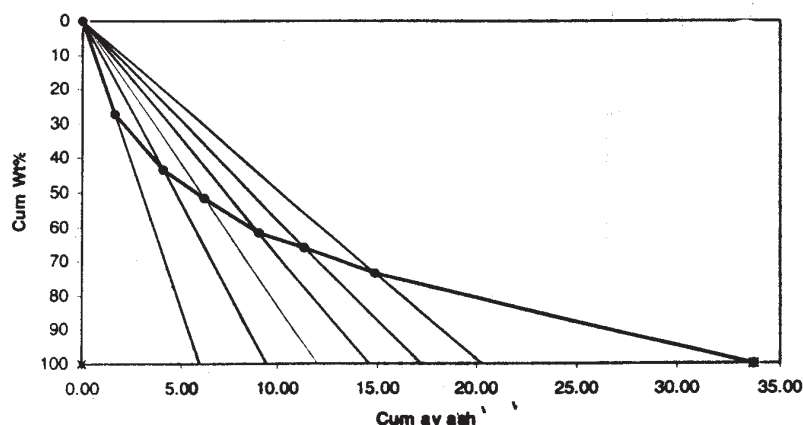


Fig. 1 : Mayer curve from float-sink analysis of Patherdih coal sample.

### The Distribution Curve

The distribution curve is a plot of the weight percent of feed reporting to clean coal as a function of specific gravity<sup>[3]</sup>. To determine the distribution curve three sets of coal analytical data are required, namely (1) recovery of clean coal, (2) float-and-sink washability analysis of the clean coal product, and float-and-sink washability analysis of the refuse. The result of float-and-sink analysis has been used for preparing the Tromp distribution curve calculation. Fig. 2 shows the distribution curve for various ash percentages.

The specific gravity of separation,  $SG_{50}$ , is defined as the value of specific gravity corresponding to 50% yield. It is the point of separation where a particle has an equal chance of appearing in the clean coal or in the refuse. In the present investigation the specific gravity of separation,  $SG_{50}$  has been evaluated using Lagrange interpolating polynomial to the experimental data.

### Reduced Efficiency Curve

A reduced partition curve can be obtained by plotting the weight percent of feed - reporting to clean coal, against the mean specific gravity of the fraction divided by the specific gravity of separation. The reduced efficiency curve remains constant for wide variations in operating conditions for a particular processing plant.

### Model Development

A number of useful empirical distribution functions are available to represent the reduced partition curve. The most commonly used are Rosin-Rammler, Exponential Sum and Logistic functions<sup>[11]</sup>.

1. Rosin-Rammler

$$y = 100[1 - \exp(-\alpha x^\beta)] \quad (1)$$

2. Exponential Sum

$$y = 100 \left[ \frac{\exp(\beta x) - 1}{\exp(\beta x) + \exp(\beta) - 2} \right] \quad (2)$$

## 3. Logistic

$$y = 100 \left[ \frac{1}{1 + \chi^{-\beta}} \right] \quad (3)$$

Where  $\chi$  is the ratio of  $SG/SG_{50}$  and  $y$  is the corresponding efficiency in the functions.  $\alpha$  and  $\beta$  are the model parameters which can be estimated from the experimental results.  $\beta$  is a measure of the sharpness of separation.

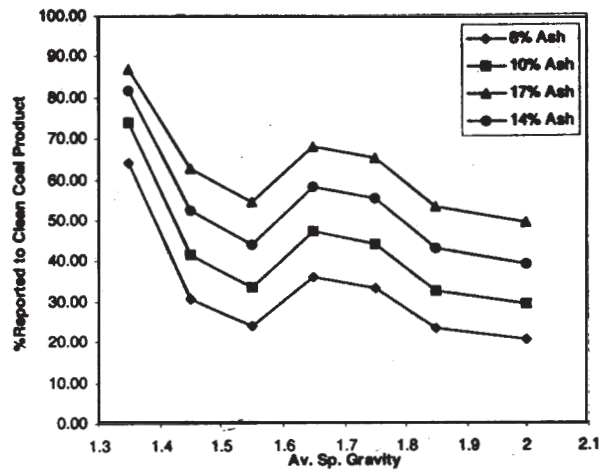


Fig. 2 : Tromp distribution curve for Patherdih sample.

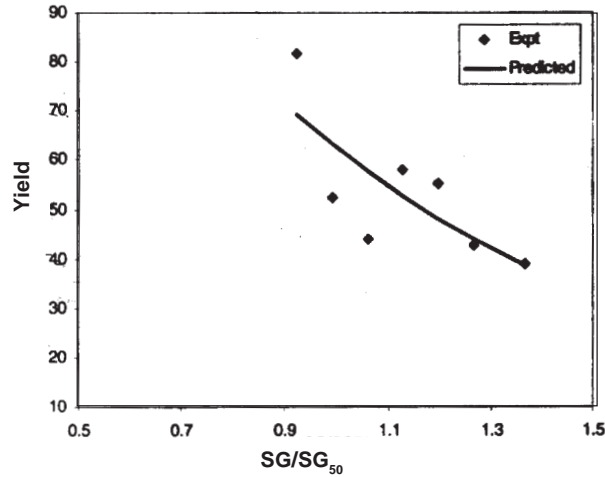


Fig. 3 : Experimental and predicted reduced efficiency curve for 14% ash with Patherdih sample.

### Parameter Estimation of Reduced Efficiency Curve

Fitting the experimental data to the model equations of reduced efficiency curve needs estimation of  $\alpha$  and  $\beta$  for the process. Least square method can be applied to determine the parameters  $\alpha$  and  $\beta$  after some simplification of the model equations.

Substituting  $y' = \frac{y}{100}$

Equation (1) can be written as  $y' = 1 - \exp(-\alpha\chi^\beta)$

Or,  $\frac{1}{1-y'} = \exp(\alpha\chi^\beta)$

Or, in logarithmic form,  $\ln \ln \left[ \frac{1}{1-y'} \right] = \ln \alpha + \beta \ln \chi$  (4)

This expression yields a linear relationship between the logarithm of the efficiency and the reduced specific gravity. The least square linear fitting of the experimental data through equation (4) will therefore provide initial values for  $\alpha$  and  $\beta$ . Fig. 3 shows the quality of fit of the Rosin-Rammler type equation.

### CONCLUSION

In this study an attempt has been made to characterize the performance of water only cyclone for washing high ash coal of Patherdih Colliery of Eastern India. It has been observed that the Rosin-Rammler type of equation can conveniently be used to represent the performance of water-only cyclone. The model parameters can be calculated by simplifying the model equation into linear forms and then applying least square technique. The parameters being known, prediction over the performance of the cyclone for changes in feed conditions is then possible.

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